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Effects of Training on Physical Performance Wearing Personal Protective Equipment

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ABSTRACT We evaluated the effects of wearing a weighted vest during 6 weeks of military-style training. Forty-three subjects were randomly assigned to a control group or a vest group (carrying 4–5 kg for 2 weeks, and 8–10 kg for 4 weeks), with 37 completing the study (17 vest, 20 control). Both groups performed stair climbing in addition to standard Marine Corps training for 1 hour, four times per week. Pre- and post-tests were performed while wearing military personal protective equipment, with the exception of the Marine Physical Readiness Test (PRT). Both groups significantly improved PRT scores (8.4% 3-mile run, 28–38% calisthenics) and an agility drill (4.4%). Significant improvements in uphill treadmill performance (6.8% vest, 3.0% control) and maximal oxygen consumption (10.7% vest, 6.8% control) were approximately twice as much in the vest versus control group, although these differences did not reach significance ($p = 0.16$ and 0.13, respectively).

INTRODUCTION

Military personnel in combat environments wear personal protective equipment (PPE), primarily consisting of a helmet and thorax-protection system (vest with ceramic plates), designed to reduce the likelihood of serious injury from the impact of small arms fire and fragments. Depending on the PPE design and mission demands, PPE has a mass of approximately 10 kg. Additionally, personnel with combat roles carry weapons, ammunition, water, rations, etc. The total external load of infantrymen has increased from approximately 13 kg at the time of Roman legionnaires to approximately 45 kg by U.S. soldiers in the first Gulf War.[1] Most recently, a study of airborne infantry in Afghanistan reported the fighting load, approach march load, and emergency approach march load were 29 kg, 43 kg, and 58 kg, respectively.[2]

During physical conditioning in the military, personnel typically perform running and calisthenics, and sometimes include loaded marching. Few studies have looked at the effects of loaded marching,[3–6] but no studies have examined the use of PPE or of weighted vests during military training. Weighted vests have been used in the training of civilians, both to improve the physical conditioning and bone density of elderly subjects,[7,8] and to improve the performance of athletes.[9–11]

We hypothesized that wearing weighted vests during military training to simulate the load of PPE would enhance physical performance during tasks when wearing PPE. As a first approach to addressing this question, we used physically active, young adult civilians placed in a modified recruit training program.

METHODS

Subjects

Forty-three subjects (22 male, 21 female) between the ages of 19 and 29 years, were recruited for the study by word of mouth from Exercise Science classes at Old Dominion University. All subjects were of low risk for cardiovascular disease,[12] and were physically active (engaging in at least 150 min per week of moderate intensity exercise, such as walking, or 75 min per week of vigorous intensity exercise, such as jogging, for the previous 3 months). No subjects were taking medication that might affect heart rate. Female subjects were excluded if they believed they may have been pregnant. The study was approved by the university institutional review board, and all subjects gave written informed consent after a discussion of the procedures and risks of the study.

After initial testing, subjects were matched for gender and the results of several test variables (treadmill time, maximal oxygen consumption, push-ups, sit-ups, 3-mile run, and body fat), and then the matched pairs were randomized into vest training and no-vest training (control) groups. Age was not used in matching, as the age range was narrow. Six subjects

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TABLE I. Subject Characteristics

Group	Gender	Time	Age (yr)	Body Mass[b] (kg)	PPE Mass[b] (kg)	Height[b] (cm)	BMI (kg × m^{-2})	% Fat[a,b]
Vest	F and M (*n* = 17)	Pre	22.8 ± 2.5	72.6 ± 12.9	11.0 ± 1.4	171 ± 7	24.7 ± 3.6	21 ± 9
		Post		71.9 ± 12.4	11.7 ± 2.8		24.5 ± 3.5	19 ± 8
	F (*n* = 9)	Pre	22.7 ± 2.7	65.5 ± 10.1	10.0 ± 0.7	167 ± 6	23.7 ± 3.6	27 ± 7
		Post		65.6 ± 10.0	10.0 ± 1.1		23.7 ± 3.7	26 ± 6
	M (*n* = 8)	Pre	22.9 ± 2.5	80.5 ± 11.4	12.1 ± 1.0	176 ± 4	25.9 ± 3.3	14 ± 5
		Post		79.0 ± 11.2	13.7 ± 2.9		25.4 ± 3.1	12 ± 3
Control	F and M (*n* = 20)	Pre	21.9 ± 2.4	74.8 ± 14.2	10.5 ± 1.7	174 ± 8	24.6 ± 3.4	20 ± 8
		Post		74.5 ± 13.9	10.8 ± 2.7		24.6 ± 3.5	18 ± 8
	F (*n* = 9)	Pre	22.1 ± 1.7	65.5 ± 10.5	9.7 ± 0.7	168 ± 3	23.3 ± 3.6	27 ± 6
		Post		65.4 ± 10.1	9.8 ± 1.7		23.3 ± 3.5	24 ± 6
	M (*n* = 11)	Pre	21.7 ± 3.0	82.3 ± 10.5	11.2 ± 2.1	179 ± 6	25.7 ± 2.7	14 ± 3
		Post		81.9 ± 11.0	11.6 ± 3.0		25.6 ± 3.1	12 ± 4
Dropouts	F and M (*n* = 6)	Pre	20.8 ± 1.5	68.9 ± 11.2	10.5 ± 1.8	172 ± 9	23.2 ± 2.8	19 ± 9
	F (*n* = 3)	Pre	20.7 ± 2.3	59.0 ± 2.8	9.3 ± 0.3	168 ± 6	21.1 ± 1.4	28 ± 3
	M (*n* = 3)	Pre	21.0 ± 0	78.7 ± 3.7	12.4 ± 1.3	177 ± 10	25.3 ± 2.1	11 ± 2

[a] Pre and post differ ($p < 0.001$, time effect). [b] Male and female differ ($p < 0.001$, gender effect).

dropped out of the study, 1 due to a knee injury experienced outside of the training and 5 due to time constraints. Characteristics of the 37 subjects who finished all training and testing are presented in Table I. The vest group had 17 subjects (8 male, 9 female), and the control group had 20 subjects (11 male, 9 female).

Testing

Over a 1-week period before training, and again after training, subjects participated in a battery of tests. Described in this report are anthropometrics, cardiopulmonary tests, and field tests.

For anthropometrics, subjects' mass, height, and skin folds were measured. Skin folds were used to estimate body fat.[13] PPE consisted of a helmet and a vest that contained rigid ceramic plates for the chest and back. The vest came in different sizes to provide an appropriate fit (small, 7.7 kg; medium, 8.2 kg; large, 10.0 kg), and thus the PPE mass varied somewhat among subjects (but did not differ between groups, Table I).

Cardiopulmonary testing included pulmonary function measures and a maximal incremental treadmill test. All subjects wore PPE for these tests. Pulmonary function testing was performed using a mass flow sensor associated with a metabolic cart (Vmax 29c, SensorMedics, Yorba Linda, California), which was calibrated against a 3-L syringe. The tests were a forced expiratory maneuver to measure forced vital capacity (FVC) and forced expired volume in 1 second (FEV_1), and a maximal voluntary ventilation (MVV) test. Pulmonary function testing was performed standing, so that the weight of the PPE vest was supported entirely by the torso and not resting on the thighs. The treadmill test was specifically designed to present a functional challenge of practical warfighting significance, carrying a load up a steep hill as opposed to unloaded running. Stages were 3 min each in duration, beginning at 3 mph (4.8 kph) and 0% grade, then 4 mph (6.4 kph) and 0% grade, followed by 5% increases in grade, while maintaining 4 mph (6.4 kph), each 3 min until reaching 20% grade. A planned increase to 4.5 mph (7.2 kph) and 20% grade was not attained by any subject in this study. For the treadmill test, subjects were fitted with a mouthpiece for collection of expired gases and a chest strap heart rate monitor (Polar, Kempele, Finland). Gases were analyzed by the Vmax metabolic cart, which was calibrated with known concentrations of O_2 and CO_2 before each test. Maximum oxygen consumption (VO_2max) was determined as the highest VO_2 over three consecutive 20-sec periods. Maximum respiratory exchange ratio (RERmax, the ratio of CO_2 production over O_2 consumption) was similarly determined as an indicator of maximum effort (i.e., RER ≥ 1.10). Subjects were verbally encouraged to exercise as long as possible.

Field testing included, in sequence, maximum push-ups in 2 min, maximum sit-ups in 2 min, maximum pull-ups to fatigue, and a separately scheduled 3-mile (4.8 km) run. These tests are a combination of the Marine Physical Fitness Test (PFT; sit-ups, pull-ups, 3-mile run; as per MCO P6100.12) and the Navy Physical Readiness Test (PRT; sit-ups, push-ups, 1.5-mile run; as per OPNAV 6110.1H). Although the Marine Corps tests females with a flexed-arm hang, the pull-up was used so that all subjects would perform the same tests for statistical purposes. Subjects also performed a 300-yd (274 m) shuttle run of twelve 25-yd (23 m) legs, and a 4 by 10-yd (9.1 m) box drill (sprint forward, side shuffle, run backward, and carioca [sideways movement with the trailing foot alternating in front and in back of the leading foot]). PPE was worn during the shuttle run and box drill but not during the PFT/PRT, as the PFT and PRT are a standard military assessments done without equipment.

Training

Training was conducted for 6 weeks. A longer time frame was initially planned to coincide with Marine recruit training, but was not possible due to logistical concerns. Subjects from both groups trained for 1 hour a day, 4 days per week under the supervision of a certified strength and conditioning specialist (National Strength and Conditioning Association). The training plan was based on Marine recruit training,[14] but modified to provide more lower body extension work (such as squats and lunges) and by replacing much of the running with stair climbing. These changes were made to place greater emphasis on the ability of the "recruits" to perform the functional task of hill climbing, as evaluated in the treadmill test. During most activities, individual subjects were encouraged to perform to the best of their ability within the time allotted, as opposed to following a set number of repetitions. For pull-up training, subjects were asked to perform as many unassisted pull-ups as possible. If this number was less than 8, another subject then assisted the individual to complete a total of 8 repetitions.

A summary of the training plan is presented in Table II. The warm-up consisted of partial squats, trunk circles, neck circles, running in place, running in place while punching forward, running in place while punching overhead, running in place while doing arm circles, and then a series of calisthenics, each performed for five, 4-count repetitions: push-ups, dirty dogs (unilateral hip abduction from all-fours position; all repetitions performed with left leg, then right leg), crunches, dive bombers (push-ups performed with buttocks initially raised and a descent that proceeds from chest to waist), donkey kicks (unilateral hip and knee extension from all fours; all repetitions performed with left leg, then right leg), side crunches, lunges and steam engines (standing knee lift with alternate elbow touch). Stair climbing was done on an indoor stairwell that rose 4.3 m or on outdoor bleachers that rose 5.1 m. Subjects were instructed to jog up and walk down and to cover as many flights as possible in the time allotted (see Table II). One day per week they sprinted a given number of repetitions (8 in week 1, 10 in week 2, 12 each in weeks 3 and 4, 15 each in weeks 5 and 6). The agility drill consisted of high knee jogging, a Z-pattern run, lateral hops over a low barrier, ladder footwork drills, and the box drill used in testing. The core series consisted of holding various plank positions (on both forearms, on right forearm, on left forearm, on both again) for 20 sec each. The cool down consisted of a brief series of calisthenics performed for five, 4-count repetitions (dirty dogs, donkey kicks, steam engines) followed by a series of static stretches held for 30 sec each: triceps, upper back, chest, iliotibial band, calf, hip and back, quadriceps, hamstrings, and adductors. Table II illustrates the typical weekly pattern, although the order of days was varied. Progression from week to week occurred by subjects climbing more flights of stairs within allotted times and performing more repetitions of calisthenics and other drills within the 1-hour training sessions.

Subjects in the vest group wore a custom-designed vest (Ironwear Fitness, Pittsburgh, Pennsylvania) that carried flexible weights and that contained hard plastic chest and back plates to mimic the movement restrictions imposed by the PPE's ceramic protective plates. Vests contained approximately 50% of the weight of the PPE vest in the first and second weeks of training (4–5 kg), and 100% of the PPE vest weight in the remaining weeks of training (8–10 kg). To assess the impact of the vests on training, subjects from both groups recorded the number of flights of stairs climbed and unassisted pull-ups performed during training.

Subjects were allowed to continue on-going outside activity and asked to record this in a log. These activities were assigned intensity levels in METs (multiples of resting metabolism) using the compendium of physical activities.[15] One MET was subtracted from the compendium value to provide net, as opposed to gross, intensity, and multiplied by the time engaged in each activity to produce MET hours of energy expenditure. This was done to evaluate whether subjects in the vest and control groups performed similar amounts of outside activity.

Statistics

Data are presented as mean ± SD. Three-way ANOVA (time: pre and post; group: vest and control; gender: male and female) with repeated measures on one factor (time) was used to compare physical characteristics between groups in Table I. Three-way ANOVA was also used to examine the effects of training; however, in examining the key variables of treadmill time and VO_2max, none of the interaction effects involving gender were significant, i.e., the main effects of time and group, and the interaction effects between group and time were not affected by the inclusion of gender in the analysis. Therefore, gender was not included as a factor and a two-way

TABLE II. Typical Training for One Week

Activity	Monday	Tuesday	Thursday	Friday
Warm up	Marine "daily 16 warm up" of dynamic stretches and calisthenics	Same as Monday	Same as Monday	Same as Monday
Workout	(1) stair climbing, 15 min (2) agility drill (3) Pull-ups, squats, push-ups, lunges (4) Core series (5) Crunches	(1) 1/4 mile or 1/2 mile runs, back extensions, crunches (2) Pull-ups, squats, push-ups, lunges (3) Core series	(1) Stair climbing, 30 min (2) Core series (3) Crunches	(1) Stair sprints (2) Agility drill (3) Core series (4) Crunches
Cool down	Marine "daily 16 cool down" of calisthenics and passive stretches	Same as Monday	Same as Monday	Same as Monday

See text for description of individual activities.

ANOVA with repeated measures on one factor (time) was used for further analysis. Regression analysis was used to compare the pretest data for treadmill time, 4.8-km time and VO_2max, to determine the basic relationship between these variables. Regression analysis was also used to compare the changes in each of these variables (pre to post), to determine the degree to which the responses of these variables to training are interrelated. Significance for all tests was set at an α level of 0.05.

RESULTS

As seen in Table I, body mass did not change following training. Percent body fat decreased ($p < 0.001$, time effect), but there was no difference between groups.

Results of cardiopulmonary testing are presented in Table III. There was a significant increase in treadmill time to exhaustion and in VO_2max following training ($p < 0.001$, time effect, for both variables). There was no group effect. However, the increases were approximately twice as large in the vest group compared to the control group (7.8% vs. 3.9% for treadmill time, 12.6% vs 7.0% for VO_2max), although, these differences did not reach significance ($p = 0.16$ for treadmill time and 0.13 for VO_2max, for group × time interaction). HRmax decreased slightly but significantly ($p < 0.01$, time effect) following training, with a strong trend ($p = 0.051$, group × time interaction) for a greater decrease in the control group. There was no group effect. The mean value of RERmax was above 1.10 during both tests in both groups, indicating maximal effort. There was a slight but significant ($p < 0.01$, time effect) decrease in RERmax following training, with no significant group effect or group × time interaction. Neither FEV_1 nor FVC changed with training, but MVV increased ($p < 0.05$, main effect for time), with no significant group × time interaction. There were no group effects for these three variables.

Results of the field testing are presented in Table IV. There were significant improvements in performance of PFT/PRT variables (push-ups, sit-ups, pull-ups, and 3-mile run) following training ($p < 0.001$ for all, time effect), but there were no group effects or group × time interactions. Given that most females performed no pull-ups, results for the males alone are presented as follows: 9.4 ± 4.6 to 12.3 ± 4.0 for the vest group, 8.6 ± 4.8 to 12.8 ± 4.0 for the control group. Shuttle run performance did not improve following training (nor was there a group effect), but box drill performance did ($p < 0.001$, time effect), with no significant group effect or group × time interaction.

To determine whether the weight of the vests affected training, analysis was performed on the number of flights of stairs climbed and unassisted pull-ups performed during training sessions. Since most females performed no unassisted pull-ups, they were not included in that analysis. For stair climbing, outdoor flights were multiplied by 1.19 to yield equivalent numbers of shorter indoor flights. The vests did not result in significantly fewer flights of stairs climbed, e.g., in the third week, which was the first week with full weight, vest subjects climbed 109 ± 19 flights vs. 114 ± 20 flights by the control group ($p = 0.44$, group effect; due to incomplete reporting by some subjects, the sample size for this analysis is 12 vest and 17 control subjects). However, significantly fewer pull-ups were performed by the vest group males in the third week, 22 ± 14 vs. 43 ± 13 ($p < 0.05$, group effect; $n = 6$ vest and 6 control).

Subjects in the two groups performed similar amounts of outside physical activity. Total MET hr over the 6 weeks of training were 118 ± 130 for the vest group, and 118 ± 112 for the control group.

Table V displays the correlations between treadmill time, 3-mile run time, and VO_2max. There were uniformly strong relationships between all of these variables in the pretest data

TABLE III. Cardiopulmonary Test Results

	FEV_1 (L)	FVC (L)	MVV* (L·min^{-1})	Treadmill Time*** (min)	VO_2max*** (ml × min^{-1} × kg^{-1})	RERmax**	HRmax** (bpm)
Vest Pre	3.64 ± 0.78	4.52 ± 1.01	144 ± 39 ($n = 16$)[a]	13.3 ± 2.5	45.7 ± 9.3	1.17 ± 0.04	188 ± 7
Post	3.66 ± 0.75	4.51 ± 0.98	150 ± 48	14.2 ± 2.1	50.6 ± 7.6	1.15 ± 0.05	187 ± 10 ($n = 16$)[a]
Control Pre	3.86 ± 0.70	4.77 ± 0.88	150 ± 36	13.3 ± 1.7	45.8 ± 6.7	1.17 ± 0.07	192 ± 7
Post	4.08 ± 0.57	4.98 ± 0.90	162 ± 31	13.7 ± 1.6	48.9 ± 5.8	1.14 ± 0.06	185 ± 12

FEV_1, forced expired volume in 1 second; FVC, forced vital capacity; MVV, maximal voluntary ventilation; VO_2max, maximum oxygen comsumption; RERmax, maximum respiratory exchange rate; HRmax, maximum heart rate. $n = 17$ vest and 20 control, except as indicated. Pre and post differ: *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. [a]Missing data points are due to equipment problems or subjects missing scheduled test times.

TABLE IV. Field Test Results

	Push-Ups*	Sit-Ups*	Pull-Ups*	3-mile Run* (min)	Shuttle Run (sec)	Box Drill* (sec)
Vest Pre	31 ± 23	50 ± 22	4.9 ± 5.6	27.6 ± 5.6	76.7 ± 9.9	12.1 ± 2.2
Post	40 ± 22	65 ± 18	6.2 ± 6.7	25.3 ± 3.9 ($n = 16$)[a]	75.6 ± 10.6	11.6 ± 2.0
Control Pre	34 ± 20 ($n = 19$)[a]	53 ± 16	5.3 ± 5.6	27.8 ± 3.8 ($n = 19$)[a]	75.9 ± 9.4	11.7 ± 1.5
Post	43 ± 17	67 ± 10	7.8 ± 6.9	25.8 ± 3.4	75.6 ± 7.7	11.2 ± 1.3

*Pre and post differ ($p < 0.001$). [a]Missing data points are due to equipment problems or subjects missing scheduled test times ($n = 17$ vest and 20 control, except as indicated).

TABLE V. Correlations Between Treadmill Time, 3-Mile Run Time, and VO_2max Results

	Treadmill vs. VO_2max		3-mile vs. VO_2max		Treadmill vs. 3-mile	
	r	*p*	*r*	*p*	*r*	*p*
Correlations Between Pretest Data						
Vest Group	0.89	<0.001	−0.84	<0.001	−0.91	<0.001
Control Group	0.90	<0.001	−0.77	<0.001	−0.82	<0.001
All Subjects	0.89	<0.001	−0.81	<0.001	−0.88	<0.001
Correlations Between Change in Score From Pretest to Post-Test						
Vest Group	0.67	0.003	0.42	0.109	0.51	0.042
Control Group	0.61	0.005	0.06	0.798	0.45	0.055
All Subjects	0.66	<0.001	0.31	0.074	0.49	0.003

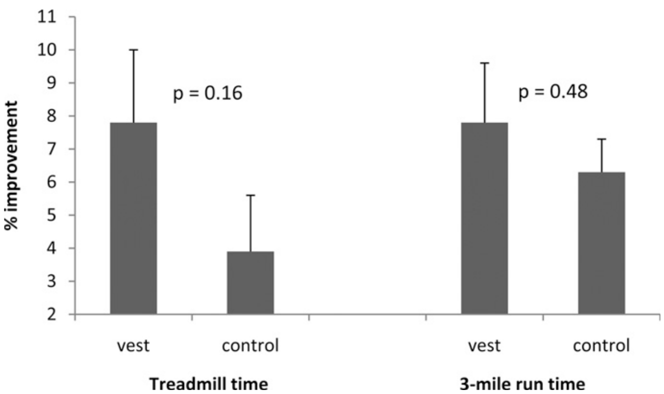

FIGURE 1. Percent improvement (mean ± SE) in treadmill time (increase) and 3-mile run time (decrease). Changes over time are significant ($p < 0.001$); differences between vest and control groups (i.e., group × time interaction) as indicated.

(absolute values of *r* ranging from 0.77 to 0.91, $p < 0.001$). Moreover, correlations for the improvement in treadmill time vs. improvement of VO_2max were significant (0.61–0.67, $p < 0.01$). However, despite a strong correlation between the baseline values of VO_2max and 3-mile run time, the improvements in these variables following training were not significantly correlated, although there was a trend in the vest group ($r = 0.42$, $p = 0.11$) but no relationship in the control group ($r = 0.06$, $p = 0.89$). There were modest correlations between the change in treadmill time and 3-mile time (*r* values 0.45–0.51), with that for the control group considered a trend ($p = 0.06$). Figure 1 illustrates the improvement in treadmill time (% increase) and 3-mile run time (% decrease) in the two groups.

DISCUSSION

This is the first study to use weighted vests to mimic PPE in military-style physical training, and no previous study has used actual PPE in training. The training program resulted in significant improvements in several physiological and performance variables in only 6 weeks. Physiologically, VO_2max increased and this was accompanied by a slight (but significant) decrease in HRmax and an increase in maximal voluntary ventilation. These are typical responses to aerobic training.[16] In terms of performance, subjects improved in virtually all measures, including treadmill time to exhaustion on an incremental hill climb, an agility drill, and all components of the PFT/PRT (push-ups, sit-ups, pull-ups, and 3-mile run). The treadmill test and agility test were performed while wearing military PPE. Subjects did not improve in a shuttle run performed with PPE.

We hypothesized that wearing a weighted vest during training would produce greater improvements in performance while wearing PPE than would training without a vest. This hypothesis was not confirmed. However, on the basis of statistical trends, we hypothesize that increasing the duration of training beyond 6 weeks and the mass of the vests above 10 kg will produce significantly greater improvements with vest versus no-vest training. In the current study, treadmill time to exhaustion and the associated VO_2max increased approximately twice as much in the vest group compared to the control group. While these differences did not reach statistical significance, the group × time interaction *p* values of 0.16 and 0.13 (respectively) are suggestive of the possibility that training for a duration longer than 6 weeks, or using a larger number of subjects, may provide significant results.

We propose that carrying a load uphill is a more appropriate task for the assessment of aerobic fitness in the military than is unloaded running on flat ground. Carrying loads uphill is an important mode of exercise in infantry combat operations, while unloaded distance running on flat ground is not typical of combat. Given this distinction, both the testing and the training of aerobic ability for infantry personnel should focus on uphill load carriage, unless it can be shown that improvement in unloaded running ability transfers to improved uphill load carriage. The correlational results of the present study argue against that. We found that pretraining performance on the treadmill test and 3-mile run were highly correlated and that both were highly correlated to VO_2max measured during the treadmill test. Strong correlations between aerobic capacity and running performance have been previously demonstrated in the literature.[17–19] However, the improvement in 3-mile run time following training was not correlated with the improvement in VO_2max, while the improvement in treadmill time was significantly correlated to improvement in VO_2max. It might be argued that these results are simply due to VO_2max being measured during the treadmill test; however, VO_2max on the treadmill test was highly correlated to 3-mile run time in the pretraining data. The failure of the improvement in 3-mile run time to correlate with the improvement in VO_2max demonstrates that the adaptations to training are mode specific, and suggests that mode-specific training is needed to optimize the ability of military personnel to operate in mountainous terrain. The technique of evaluating change in physiological measures and change in performance following training was used in a recent study by Esfarjani and Laursen,[19] who found a significant correlation between improvement in VO_2max and improvement in 3,000-m running performance ($r = 0.76$) in athletes, which is similar to our finding for changes in treadmill time and VO_2max, as opposed to our lack of a significant correlation between changes in 3-mile run time and VO_2max. Most notably, the control group, training with unloaded stair climbing, exhibited a correlation coefficient of only 0.06 for these two variables. We hypothesize that standard aerobic training in the military, running on flat ground without a load, would also show a lack of correlation with aerobic adaptations during uphill load carriage.

The amount of weight used in the vests during training, 4–5 kg for 2 weeks and 8–10 kg for the remaining 4 weeks, was chosen to mimic PPE. However, during combat operations military personnel carry considerably more weight, often 30 kg and sometimes as much as 60 kg.[2] The weight used in this study was challenging for upper body training, but not sufficiently challenging for lower body training. We base this conclusion on the fact that subjects in the vest group performed considerably fewer pull-ups than control subjects during the training, but were able to climb a similar number of flights of stairs. We hypothesize that gradually increasing the vest weight above the levels used in this study may prove more beneficial for lower body training and is likely to produce statistically significant differences between vest and control groups.

Although this is the first use of simulated PPE in military-style training, other studies have used loaded marching as one component of military training. Rudzki had Australian Army recruits perform the aerobic portion of their training either by unloaded running or by loaded marching.[3] Loads progressed to 29 kg. Both groups increased VO_2max to a similar degree, but VO_2max was unfortunately estimated, not measured, and derived from a bicycle ergometer test, which is an inappropriate mode of testing for individuals trained in running or marching. Knapik et al. had U.S. Army infantrymen train in four groups using different frequencies of loaded marching: zero, once per month, twice per month, or four times per month.[4] Loads progressed to 34 kg. On a post-training loaded march carrying 46 kg, the groups that had marched two or four times per month were faster than the groups that marched less in training. Harman et al. had civilian women perform military-style training, including a loaded march once per week.[5] The final load in training varied between subjects (as individually tolerated) from 11 to 34 kg. Training resulted in a significant increase in marching speed while carrying 34 kg; however, no control group was used in the study. Most recently, Harman et al. had two groups of male civilians do military-style training.[6] One group included loaded marching once per week carrying a weight that varied between subjects up to a maximum of 33 kg. Several performance tests were done while carrying a load, along with a PRT and an unloaded treadmill VO_2max test. Both groups improved in every measure, with the only differences between groups being greater improvement by the group that did no loaded marching in the unloaded 2-mile run and, surprisingly, in the 18-kg loaded obstacle course. These studies used limited training with load (infrequent marching) and the results, while generally positive, were correspondingly limited. The one study that compared different frequencies of loaded marching did find that greater frequency was better, but the greatest frequency was only once per week and the interpretation of the results was limited by an inability to compare pre- and post-training data.[4] Taken together these studies suggest that training with load is beneficial and that a greater frequency should be studied.

Weighted-vest training has been used in nonmilitary settings. Several studies have been done with elderly subjects, in which vests were used to apply resistance during weight-bearing activities to improve functional movement and bone density.[7,8] More relevant to military application is a series of studies done by Bosco and colleagues in the 1980s on track and field athletes.[9–11] Elite athletes continued their usual training, with half wearing a weighted vest during all waking hours. The vest weight was typically about 10% of body weight, and significant improvements in several measures of jumping ability were found in jumpers and sprinters who wore vests,[9,10] but no improvements in aerobic ability were observed in long-distance runners and cross-country skiers.[11] These results support the specificity of training and testing. The added load during jump training improved lower body strength and power for jumping tasks, but did not result in improved VO_2max during an unloaded treadmill test among endurance athletes who, unlike military personnel, do not carry a load in the competitive environment.

CONCLUSIONS

This is the first study to use weighted vests or personal protective equipment in military-style training or testing. A 6-week training program using vests with a mass of approximately 10 kg resulted in significant increases in several physiological and performance measures. Subjects performing similar training without vests experienced similar improvements in most measures. Performance in a loaded treadmill hill climb, and in the associated VO_2max, increased twice as much with vest training compared to no-vest training. However, these differences did not reach statistical significance. We suggest that training with more heavily loaded vests for a longer period of time should be investigated.

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